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RESEARCH PAPER

Examining the Optimal Method to Extract Logging Residues from Small-Scale Forestry in the Nasunogahara Area, Tochigi Prefecture, Japan

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Abstract This study examines the optimal method to extract logging residues from small, fragmented and scattered forests separately from the mechanized operational systems used on aggregated forestry operation sites. First, small-scale logging systems operated by a private logging contractor and an individual forest owner were investigated. Regression equations for estimating felling and processing cycle times were established as a function of stem and log volumes, respectively. Equations to estimate the forwarding and transporting cycle times were established as a function of the forwarding and transporting distances using the forwarding and transporting velocities, respectively. Then, equations to estimate productivities and costs were established with the cycle times, volumes and hourly operational expenses consisting of labour and machinery expenses. Finally, costs of the small-scale systems—mini-forwarder and 4 t truck operated by a private logging contractor, and manual logging and light truck operated by an individual forest owner—were estimated and compared with the mechanized operation system operated by the Forest Owners' Association. The mechanized operation system was found to have the highest cost and could not compete for small forestry operational sites and small stem volumes. The small-scale systems could be effective for harvesting small areas. This was especially true when conducting extracting operations without machines, as done by the individual forest owner, and transporting operations by a

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private logging contractor, in which the hourly income of the individual forest owner was higher than the hourly labour expenses.

Keywords Logging residue extraction · Private logging contractor · Individual forest owner · Forest Owners' Association · Manual logging · Mechanized logging

Introduction

The oil crises of the 1970s spurred research about bioenergy. Although promising results were obtained from the studies (Agriculture, Forestry and Fisheries Research Council Secretariat 1991), a project was not implemented as a system in an actual site because the crude oil price stabilized at a lower level and the expected demand were reduced in Japan. Nowadays, however, biomass as a renewable and carbon–neutral energy resource is becoming of interest again as a measure against climate change and to improve energy security. Among various biomass resources, woody biomass particularly attracts much attention in Japan. This is because not only its amount is abundant, but also the energy utilization of woody biomass is expected to contribute to revitalizing the forest and forest products industries, which have been depressed for the last 30 years. Maintaining the relevant ecological, economic and social functions of man-made forests, which are behind in tending, is also important.

An agrarian organization in the Nasunogahara area in Tochigi prefecture is willing to conduct thinning operations and extract thinned wood for biomass power generation, in cooperation with the Forest Owners' Association in Nasushiobara, to nurture river resources as well as maintain forests for soil and water conservation. Nakahata et al. (2011) investigated current operations for extracting thinned woods by the Forest Owners' Association in Nasushiobara and mechanized operations of the Forest Owners' Association in Nasu. Improvements in efficiencies and costs by mechanization were examined. Nakahata et al. (2011) concluded that profits would be increased by selling logging residues at the price of 1,000 yen/m^3 at landings (100 yen $\approx$ 1 USD), in addition to selling timber to a log market using a mechanized operation system on aggregated forestry operation sites that merged small forests for large forestry machinery to work efficiently.

Forest ownership in Japan is characterized by a large number of small, fragmented and scattered forest owners (Forestry Agency 2009), and this is true for the region studied. Therefore, it is difficult to aggregate forestry operation sites in this region even though private forests are located on relatively gentle slope areas and forest road networks are well established. Thus, the optimal method to extract logging residues from such small, fragmented and scattered forests should be examined separately from the mechanized operational systems used on aggregated forestry operation sites.

In many regions of the world, small-scale harvesting machines have been used in forestry where terrain condition and size of forest operations are not limiting (Akay 2005). In some European counties, farm tractors are commonly used for various forest harvesting tasks including felling, processing, extraction and transportation in

small-scale logging systems. Especially, a standard winch and a sulky can be fitted to any tractor at relatively low cost, and can be used for part-time forest operations (Spinelli and Magagnotti 2012). This simple technology has strong potential for effective deployment in farm forestry in developing countries. On the other hand, various animal species (oxen, horses, buffalos and mules) have been used for skidding operations. Oxen are commonly used for skidding in Turkey (Melemez et al. in press). Furthermore, over 80 % of extraction operations in Turkish forest are conducted with manpower as skidding or sliding, but these methods have technical, ergonomic and environmental problems. To overcome these problems, manual extractions with plastic chutes has been examined (Eroglu et al. 2007). In Japan, mini-forwarders were commonly used for forwarding operations by small-scale private forest owners and logging companies (Oh et al. 2004). Furthermore, light trucks with 350 kg loading capacity are also commonly used for commuting to the forests and transporting small sized logs.

Niyodo, a local community in the Kochi area of southwestern Japan, has recently started a government-subsidized woody biomass utilization project. The project collects logging residues for a processing plant using three systems: (1) a large-scale logging contractor operation, (2) a medium-scale system operated by the Forest Owners' Association, and (3) a small-scale system operated by an individual forest owner. Although the expected largest source of logging residues was the large-scale system, the small-scale systems procurement was, in fact, the largest (Suzuki et al. 2009). Therefore, a small-scale system used by individual forest owners with mini-forwarders and light trucks would be important for extracting logging residues from such small, fragmented and scattered forests all over Japan as well as in some other regions of the world with manual logging. This study examined the methods for extracting logging residues from such small, fragmented and scattered forests.

The Study Sites

The study was conducted by the following steps: (1) small-scale systems operated by a private logging contractor and an individual forest owner were investigated, (2) cycle times were analyzed, (3) equations to estimate productivities and costs were established, and (4) costs of the small-scale systems—mini-forwarder and 4 tonne truck operated by a private logging contractor, and manual logging and light truck operated by an individual forest owner—were estimated and compared with the mechanized operation system operated by the Forest Owners' Association. This study assumed that a private logging contractor and a worker of the Forest Owners' Association were professional whereas an individual forest owner was amateur and had recently commenced forestry operations from logging residues extraction.

Two study sites were chosen in Nasushiobara, Tochigi prefecture, Japan. Study site 1 was a 45-year-old Japanese cedar plantation. Its area was 0.26 ha, with average slope 3.5 %, stand density 2,000 stem/ha, average diameter at breast height (DBH) 24.5 cm, average tree height 23.5 m and average stem volume 0.56 m^3/stem. Thinning operations and thinned wood extractions were conducted by chainsaw felling and processing (Kyoritsu CS42RSH/40RV95), mini-forwarder

Fig. 1 Loading to mini-forwarder (**a**), forwarding (**b**), unloading from mini-forwarder with truck crane by a private logging contractor (**c**), and loading to a light truck by an individual forest owner (**d**)

forwarding (Chikusui Canycom Yamabiko BFY1001, 7.4 kW engine horsepower), and truck transportation (loading capacity 4 t) to a chip production factory by a private logging contractor (Fig. 1). The thinning rate of stems was 26.8 %. The average DBH, tree height and stem volume of the thinned wood were 16.8 cm, 17.7 m and 0.25 m^3/stem, respectively. Therefore, the thinned wood volume was 134 m^3/ha and the thinning rate of volume was 12.0 %.

Study site 2 was a 42-year-old Japanese cypress plantation forest. Its area was 0.25 ha, with average slope 19.4 %, stand density 1,450 stem/ha, average DBH 25.5 cm, average tree height 12.6 m and average stem volume 0.32 m^3/stem. Selection felling operations and felled wood extractions were conducted with chainsaw felling and processing (Husqvarna 36) by an individual forest owner, fork-shovel logging (Komatsu PC40 with Marujun IFZ55) and truck transportation (loading capacity 2 t) by a private logging contractor. Residual trees were naturally generated broadleaf species and some well-grown Japanese cypress. The average DBH, tree height and stem volume of the felled wood were 22.2 cm, 11.8 m and 0.30 m^3/stem, respectively.

Research Method

Time study was conducted to analyse cycle times and productivities. Felling, processing, forwarding and transporting by a private logging contractor were

investigated in study site 1 whereas only felling and processing operations by an individual forest owner were investigated in study site 2. The felling and processing cycle times were related to the stem and log volumes, respectively, using regression analysis. The forwarding and transporting times were related to the forwarding and transporting distances, respectively, using regression analysis.

The productivities per productive hour, P_{E0} (m^3/h) were estimated with average cycle time, T (s/cycle) and average volume, V (m^3/cycle):

$$P_{E0} = \frac{3{,}600 \times V}{T} \tag{1}$$

The productivities per scheduled hour, P (m^3/h), were estimated by multiplying the productivities per productive hour by 3/4 using the method of Kamiiizaka et al. (1990).

The direct operational expenses, OE (yen/m^3) were estimated using productivities per scheduled hour and hourly operational expenses consisting of labour and machinery expenses. Labour expenses, OL (yen/h), were set at 1,300 yen/h. Machinery expenses, OM (yen/h), consisted of maintenance, management, depreciation, and fuel and oil expenses (Table 1).

$$OE = \frac{OL + OM}{P} \tag{2}$$

Finally, the costs of the small-scale systems—mini-forwarder and 4 t truck operated by a private logging contractor, and manual logging and light truck operated by an individual forest owner—were estimated and compared with the mechanized operation system operated by the Forest Owners' Association. Costs were estimated for the six following operational systems: (1) all operations conducted by a private logging contractor; (2) felling, processing and extracting operations by the individual forest owner and transportation by a private logging contractor; (3) operational system 2 without the labour expenses of the individual forest owner; (4) all operations conducted by the Forest Owners' Association; (5) all operations conducted by the individual forest owner; and (6) operational system 5 without the labour expenses of the individual forest owner. In operational systems 3 and 6, the labour expenses of the individual forest owners were not considered because the individual forest owners were assumed to obtain income from selling logging residues rather than conducting extraction operations. Thus, hourly incomes of operational systems 3 and 6 were estimated from the profits and operational times of the individual forest owners rather than using the 1,300 yen/h labour expense. Revenues were 3,000 yen/m^3 at a biomass power generation plant and 1,000 yen/m^3 at landings. Equations established by Nakahata et al. (2011) were used to estimate the costs conducted by the Forest Owners' Association (Table 2).

In addition to these direct expenses, machinery transportation expenses were estimated as 5,000 yen/machine (following Nakahata et al. 2011). The number of machines to be transported was one for operational system 1, three for operational system 4, and zero for the other systems. Stand conditions for estimations were assumed to be the same as study site 1. Machinery transportation expenses were fixed costs and the expenses per extraction volume changed according to the

Table 1 Machinery expenses

Machine	Machine price (yen)	Life (year)	Operating time (h/year)	Life time depreciation (%)	Repairs and maintenance rate (%)*	Annual management rate (%)**	Fuel oil (yen/h)	Machinery expenses (yen/h)
Chainsaw	137,000	3.0	1,350	90	85	6.5	353	419
Mini forwarder	1,943,000	5.0	1,620	90	96	6.5	48	572
Light truck[a]	850,000	5.0	1,100	90	40	10	292	570
4-t truck[b]	3,634,000	5.0	1,650	90	40	10	528	1,320

Source Forestry mechanization society (1999), Japan Forest Technology Association (2010), Sawaguchi (1996), Zenkoku Ringyo Kairyo Fukyu Kyokai (2001)

* Life time repairs and maintenance expenses were repairs and maintenance rates of machine prices

** Annual management expenses were annual management rates of machine prices

[a] Loading capacity of 350 kg; [b] loading capacity of 4 t

Table 2 Direct operational expenses for the Forest Owners' Association

Machine	Operation	Expense (yen/m^3)
Chainsaw and grapple-loader	Felling and bunching	$(138.7Vn + 304.2)/Vn$
Processor	Processing	$(222.2Vl + 241.5)/Vl$
Forwarder	Forwarding	$564 + 0.50L_F$
8-t truck	Transportation	$627 + 48.7L_T$

Vn is the stem volume (m^3/stem), *Vl* is the log volume (m^3/stem), L_F is the forwarding distance (m), and L_T is the transportation distance (km)

extraction volume. In this study, the extraction volumes per areas were also assumed to be fixed. Extraction volumes changed according to site areas. Therefore, site areas were examined in this study. The extraction distances were estimated with 0.5 × road density (m/ha) × site area (ha), where road density was assumed to be 200 m/ha. The transporting distance was 10 km from study site 1 to a woody biomass power generation plant. Transporting distances affected productivities and costs of transporting operations. Therefore, transporting distances were also examined in this study.

Results

The cycle time and productivity of chainsaw felling and processing operations are listed in Table 3. The average cycle time and productivity of felling operations by the private logging contractor at study site 1 were estimated at 87 s and 10.34 m^3/h, respectively, with an average stem volume for the thinned wood of 0.25 m^3/stem. The average cycle time and productivity of felling operations by the individual forest owner at study site 2 were estimated at 137 s and 7.88 m^3/h, respectively, with an average stem volume for the thinned wood of 0.30 m^3/stem. The productivity of the individual forest owner was lower than that of the private logging contractor although the average stem volume of felled wood at study site 2 was larger than that at study site 1.

Times, t_{F1} and t_{F2} (s/stem), of undercut, back cut, and wedge from study sites 1 and 2, respectively, were related to the stem volume, *Vn* (m^3/stem), of the felled trees (Fig. 2).

$$t_{F1} = 133.7Vn - 4.5 \tag{3}$$

$$t_{F2} = 389.4Vn - 4.9 \tag{4}$$

Moving times at study sites 1 and 2 were 27 s/stem and 44 s/stem, respectively. However, these values were lower than the 57 s/stem result of the Forest Owners' Association (Nakahata et al. 2011) because the association's moving time included the selection of felling trees. The moving times in this study did not include selection of felling trees because selection had been completed before operations. Furthermore, hang-up times at study sites 1 and 2 were only 14 and 0 s/stem, respectively, compared with 43 s/stem (Nakahata et al. 2011) by the Forest Owners'

Table 3 Cycle time and productivity of chainsaw felling and processing

Parameter	Study site 1 Logging contractor		Study site 2 Forest owner		Nakahata et al. (2011) Owners' association	
Moving time (s)	27	(9.3)	44	(10.0)	57	(12.1)
Undercut time (s)	11	(3.8)	24	(5.4)	21	(4.4)
Back cut time (s)	10	(3.5)	36	(8.1)	33	(7.0)
Wedging time (s)	5	(1.7)	33	(7.5)	12	(2.5)
Hang-up time (s)	14	(4.9)	0	(0.0)	43	(9.1)
Processing time (s)	222	(76.8)	305	(69.0)	307	(64.9)
Cycle time (s)	309	(100.0)	442	(100.0)	473	(100.0)
Felling						
Stem volume (m^3/stem)		0.25		0.30		0.41
Productivity (m^3/h)		10.34		7.88		8.89
Processing						
Log volume (m^3/stem)		0.22		0.18		0.32
Productivity (m^3/h)		3.57		2.12		3.75

The figures in parentheses were percentages of operation times

Association because there were few investigated hang-ups in this study. This would not be the normal situation when conducting thinning operations. Therefore, the felling cycle time, T_{F1} and T_{F2} (s/stem), including moving times with the selection of felling trees and hang-up times from the Forest Owners' Association as reported by Nakahata et al. (2011), in addition to the time of undercut, back cut, and wedge, were estimated using Eqs. (5) and (6).

$$T_{F1} = 133.7Vn + 95.5 \tag{5}$$

$$T_{F2} = 389.4Vn + 95.1 \tag{6}$$

Productivities per scheduled hour and the direct operational expenses were estimated using the Eqs. (1) and (2) with the cycle times and the average stem volumes (Tables 4, 5).

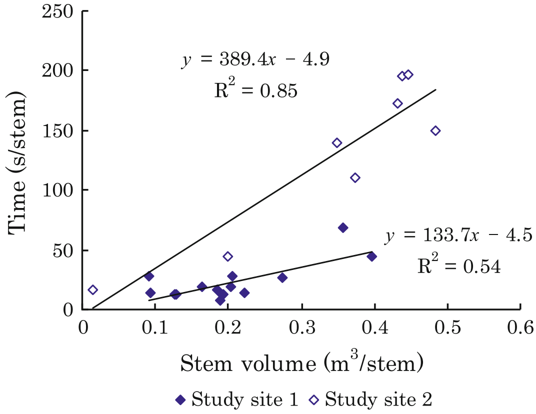
The average cycle time and productivity of processing operations at study site 1 were estimated at 222 s and 3.57 m^3/h, respectively, with an average log volume of 0.22 m^3/stem (Table 3). The average cycle time and productivity of processing operations at study site 2 were estimated at 305 s and 2.12 m^3/h, respectively, with an average log volume of 0.18 m^3/stem. The productivity of the individual forest owner was lower than that of the private logging contractor because of smaller log volumes and less skill.

The cycle time, T_{P2} (s/stem), of processing operations at study site 2 was related to the log volume Vl (m^3/stem) from felled trees (Fig. 3).

$$T_{P2} = 1{,}021.9Vl + 177.7 \tag{7}$$

However, the processing operations of some felled trees at study site 1 were conducted simultaneously. Therefore, the cycle time T_{P1} (s/stem) of the processing operation for each tree at study site 1 could not be measured. The average cycle time

Fig. 2 Times of undercut, back cut and wedge versus stem volumes



of processing operations at study site 1 of 222 s was similar to the 233 s estimation with the average log volume at study site 1 of 0.22 m^3/stem using the equation developed by Nakataha et al. (2011) from the operations by the Forest Owners' Association in this region. Therefore, this study assumed the operational efficiency of the private logging contractor at study site 1 was the same as that of the Forest Owners' Association. Thus, the same equation developed by Nakataha et al. (2011) was used for the private logging contractor.

$$T_{P1} = 690.0Vl + 81.0 \tag{8}$$

Productivities per scheduled hour and the direct operational expenses were estimated using the Eqs. (1) and (2) with the cycle times and the average log volumes from stems (Tables 4, 5).

The cycle time and productivity of the mini-forwarder forwarding operations are reported in Table 6. The average cycle time, forwarding distance, and volume by the private logging contractor at study site 1 were 1,037 s, 92.2 m, and 1.23 m^3/cycle, respectively. Therefore, productivity was estimated at 4.27 m^3/h.

The cycle time, T_{F1} (s/cycle), of forwarding operations by mini-forwarder at study site 1 was related to forwarding distance, L_F (m/cycle), travel velocities of out hauling and in hauling, v_{F1} and v_{F2} (m/s), and the loading and unloading time, tf_F (s/cycle).

$$T_F = tf_F + L_F(1/v_{F1} + 1/v_{F2}) \tag{9}$$

From the results in Table 6, travel velocities of out hauling and in hauling, v_{F1} and v_{F2}, were 0.51 and 0.41 m/s, respectively, and the loading and unloading time tf_F was 622 s/cycle.

$$T_{F1} = 622 + 4.40L_F \tag{10}$$

Productivities per scheduled hour and the direct operational expenses were estimated using the Eqs. (1) and (2) with the cycle time and the average forwarding volume of 1.23 m^3/cycle (Table 4).

In the small-scale systems operated by individual forest owners, some extracting operations of small-sized logs were conducted without machinery (Fig. 1).

Table 4 Direct operational expenses for a private logging contractor

Machine	Operation	Productivity (m^3/h)	Expense (yen/m^3)
Chainsaw	Felling	$2{,}700Vn/(133.7Vn + 95.5)$	$(85.1Vn + 60.8)/Vn$
Chainsaw	Processing	$2{,}700Vl/(690.0Vl + 81.0)$	$(349.3Vl + 51.6)/Vl$
Mini-forwarder	Forwarding	$3{,}321/(622 + 4.40L_F)$	$351 + 2.48L_F$
4-t truck	Transportation	$11{,}556/(1{,}228 + 240L_T)$	$278 + 54.4L_T$

Vn is the stem volume (m^3/stem), *Vl* is the log volume (m^3/stem), L_F is the forwarding distance (m), and L_T is the transportation distance (km)

Table 5 Direct operational expenses for an individual forest owner

Machine	Operation	Productivity (m^3/h)	Expense (yen/m^3)
Chainsaw	Felling	$2{,}700Vn/(389.4Vn + 95.1)$	$(247.9Vn + 60.6)/Vn$
Chainsaw	Processing	$2{,}700Vl/(1{,}021.9Vl + 177.7)$	$(650.6Vl + 113.1)/Vl$
Manual	Forwarding	$108/4.26L_F$	$51.28L_F$
Light truck	Transportation	$1{,}404/(900 + 240L_T)$	$1{,}199 + 319.7L_T$

Vn is the stem volume (m^3/stem), *Vl* is the log volume (m^3/stem), L_F is the forwarding distance (m), and L_T is the transportation distance (km)

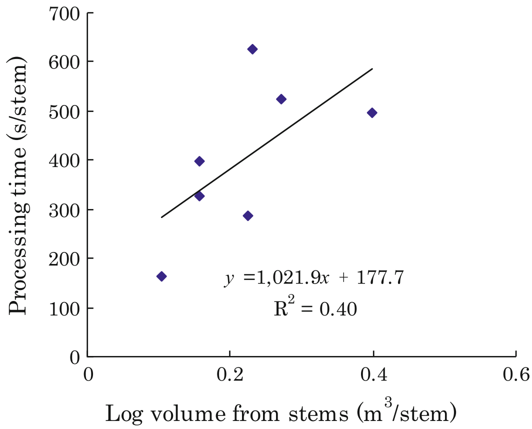


Fig. 3 Times of processing operation versus log volumes

However, extracting operations by individual forest owners without machinery were not investigated. Therefore, walking velocity and the loading and unloading time tf_F were assumed to be 1.7 km/h (0.4 m/s) following Sawaguchi (1996) and 0 s/cycle, respectively. The cycle time, T_{F2} (s/cycle), of extracting operations by individual forest owners without machinery for study site 2 was estimated by substituting these values into the Eq. (9).

$$T_{F2} = 4.26L_F \tag{11}$$

Extracting operations by individual forest owners without machinery was assumed to be conducted at the rate of one log per cycle. Thus, the productivity per

scheduled hour and the direct operational expense were estimated using the Eqs. (1) and (2) with the cycle time and the average log volume of 0.04 m^3/cycle (Table 5).

The results of truck loading and unloading operations are listed in Table 7. The preparing, loading and unloading times by the private logging contractor at study site 1 were 283, 505, and 440 s, respectively. The loading volume was 4.28 m^3/cycle.

The cycle time, T_{T1} (s/cycle), of transporting operations by trucks with 4 t loading capacities at study site 1 was related to transporting distances, L_T (km/cycle), travel velocity, v_T (km/h), and the loading and unloading time, tf_T (s/cycle).

$$T_T = tf_T + 7{,}200 L_T / v_T \tag{12}$$

From the results in Table 7, the loading and unloading time tf_T was 1,228 s/cycle. The travel velocity v_T was assumed to be 30 km/h (Sawaguchi 1996).

$$T_{T1} = 1{,}228 + 240 L_T \tag{13}$$

Productivities per scheduled hour and the direct operational expenses were estimated using the Eqs. (1) and (2) with the cycle time and the average transporting volume of 4.28 m^3/cycle (Table 4).

In a small-scale system operated by individual forest owners, some transporting operations of small-sized logs were conducted using light trucks with a 0.35 t loading capacity. Some preliminary investigations were conducted on loading and unloading operations (Fig. 1). As a result, the loading and unloading time, tf_T, was 900 s/cycle. The travel velocity v_T was assumed to be 30 km/h (Sawaguchi 1996). The cycle time, T_{T2} (s/cycle), of transporting operations with light trucks by individual forest owners at study site 2 was estimated by substituting these values into the Eq. (12).

$$T_{T2} = 900 + 240 L_T \tag{14}$$

The transporting volume was estimated as 0.52 m^3/cycle with a 0.35-t loading capacity for the light trucks, and a 0.68 t/m^3 bulk density with the 80 % dry base water content for the small-sized logs (following Yamaguchi et al. 2010).

Table 6 Cycle time and productivity of mini-forwarder forwarding

Parameter	Study site 1 Logging contractor	
Out hauling time (s)	169	(16.3)
Loading time (s)	381	(36.7)
Moving during loading time (s)	60	(5.8)
In hauling time (s)	246	(23.7)
Unloading time (s)	181	(17.5)
Cycle time (s)	1,037	(100.0)
Average forwarding volume (m^3/cycle)		1.23
Average forwarding distance (m)		92.2
Average out hauling speed (m/s)		0.51
Average in hauling speed (m/s)		0.41
Productivity (m^3/h)		4.27

The figures in parentheses were percentages of operation times

Table 7 Truck loading and unloading time and volume (loading capacity of 4 t)

Parameter	Study site 1 Logging contractor	
Preparing time (s)	283	(23.1)
Loading time (s)	505	(41.1)
Unloading time (s)	440	(35.8)
Total time (s)	1,228	(100.0)
Loading volume (m^3/cycle)		4.28

The figures in parentheses were percentages of operation times

Productivities per scheduled hour and the direct operational expenses were estimated using the Eqs. (1) and (2) with the cycle time and the average transporting volume of 0.52 m^3/cycle (Table 5).

The cost estimations are shown in Figs. 4 and 5. In the case of selling logging residues at a woody biomass power generation plant, system 3 had the lowest cost at 1,227 yen/m^3, followed by system 6, because the labour expense of the individual forest owner was not considered in systems 3 and 6. However, the 20 m extraction distance on the site area of 0.2 ha would be the limiting distance for extracting operations by individual forest owners without machinery. For site areas greater than 0.2 ha, system 1 with all operations conducted by a private logging contractor was the system with the lowest cost.

For selling logging residues at landings, transporting operations were not included, which made systems 2 and 3 the same as systems 5 and 6. As in the selling of logging residues at a plant, systems 3 and 6 had the lowest costs at 405 yen/m^3, followed by system 1.

For selling logging residues at a plant with 3,000 yen/m^3, systems 1, 3, and 6 were profitable, but systems 2, 4, and 5 were not (Fig. 4). For selling logging residues at landings with 1,000 yen/m^3, only systems 3 and 6 were profitable, whereas system 1 became in deficit (Fig. 5). Because the difference in logging residue prices between the plant and landing was higher than the transportation expenses, the profit of system 1 when selling logging residues at landings without transportation was lower than that of system 1 when selling logging residues at a plant with transportation.

The hourly incomes were estimated from the profits and operational times of the individual forest owner (Fig. 6). The hourly incomes of system 3 when selling logging residues at a plant was the highest at between 990 and 1,479 yen/h if the site area was less than 0.20 ha. The hourly incomes of the other systems were below 500 yen/h. Therefore, system 3, with extracting operations by the individual forest owner without machinery and transporting operations by a private logging contractor, could be effective on small site areas and its hourly income was higher than the hourly labour expenses.

The cost estimation according to transporting distances with the 0.20 ha site area is shown in Fig. 7. In the case of selling logging residues at a plant, system 3 had the lowest cost, followed by system 6 because the labour expense of the individual forest owner was not considered in systems 3 and 6. However, system 1 had lower

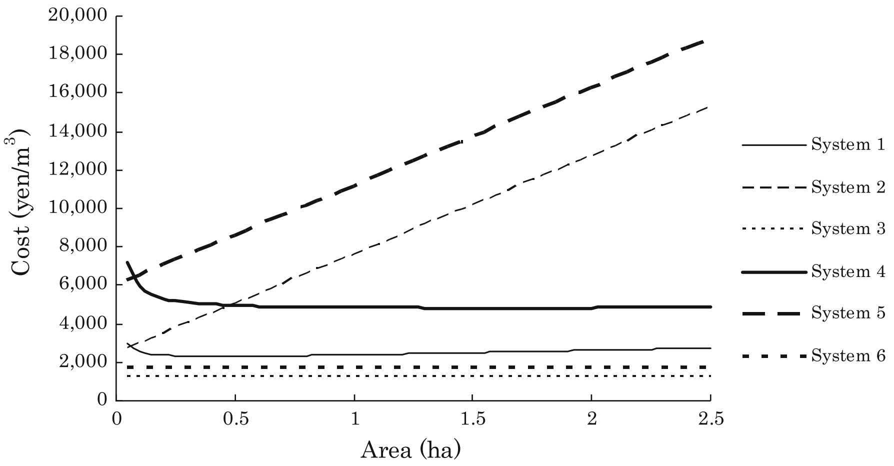


Fig. 4 Costs versus site areas from selling logging residues to a plant

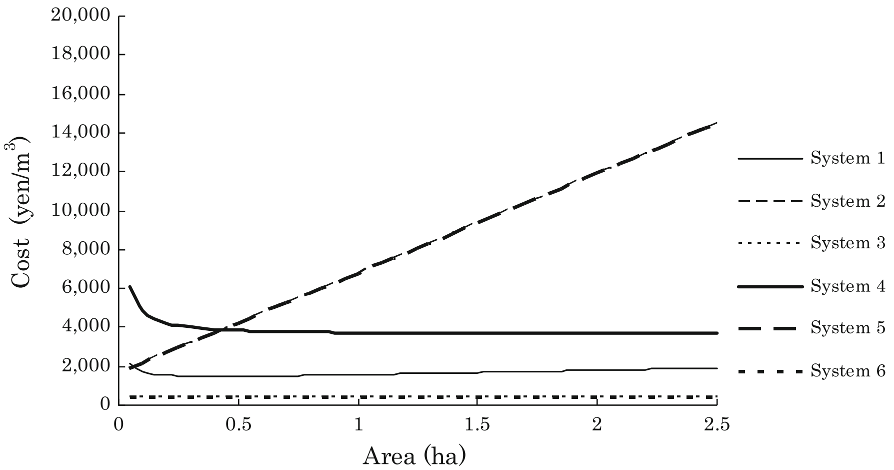


Fig. 5 Costs versus site areas from selling logging residues at landings

cost than system 6 over the 25 km transporting distance because of higher transporting expenses with light truck.

Discussion

The 10.34 m^3/h productivity of chainsaw felling by the private logging contractor was higher than the 8.89 m^3/h productivity by the Forest Owners' Association as reported by Nakahata et al. (2011). Conversely, the productivity of the individual forest owner was lower than that of the Forest Owners' Association as reported by Nakahata et al. (2011). The 3.57 m^3/h productivity of processing operations by a

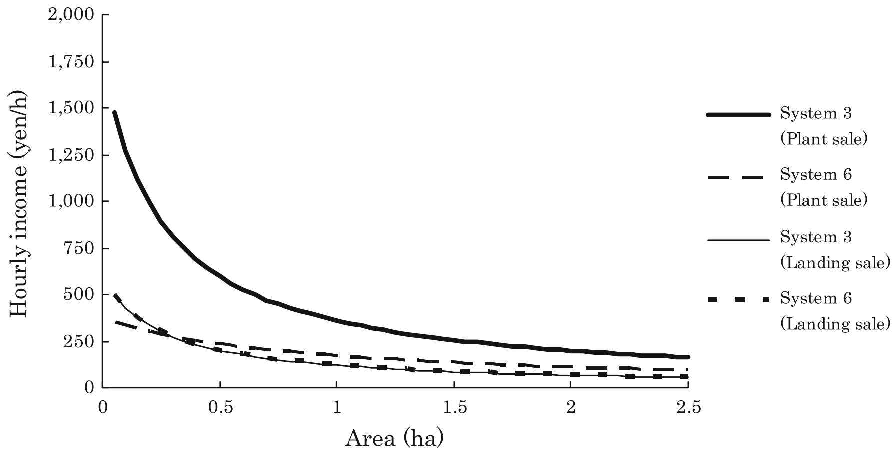


Fig. 6 Hourly incomes versus site areas

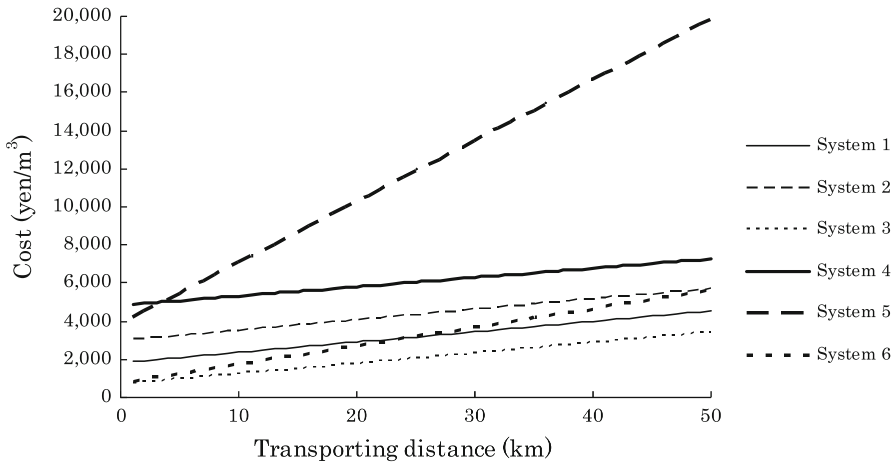


Fig. 7 Costs versus transporting distances from selling logging residues to a plant

private logging contractor was lower than the 3.75 m^3/h productivity by the Forest Owners' Association as reported by Nakahata et al. (2011) because of smaller log volumes. The 2.12 m^3/h productivity of the individual forest owner was lower than that of the Forest Owners' Association as reported by Nakahata et al. (2011) because of smaller log volumes and his skill. Skill levels of a private logging contractor, an individual forest owner, and a worker of the Forest Owners' Association may vary widely. Level of skill and whether operational conditions are the same must be discussed among a private logging contractor, an individual forest owner, and the Forest Owner's Association. However, it was difficult to determine level of skill and whether operational conditions were same with these limited data. Therefore, more investigation and examination of different level of skill and operational conditions should be conducted. However, this study assumed a private logging contractor and

a worker of the Forest Owners' Association were professional while an individual forest owner was amateur and had recently commenced forestry operations from logging residues extraction. Thus, same equations to estimate productivities and costs of chainsaw processing operations by a private logging contractor and the Forest Owners' Association, and assumptions of lower productivities and higher costs of an individual forest owner than a private logging contractor and the Forest Owners' Association could be valid.

The 4.27 m^3/h productivity of the mini-forwarder forwarding operations by the private logging contractor was lower than the 5.07 m^3/h productivity by the Forest Owners' Association as reported by Nakahata et al. (2011) with the 92.2 m average forwarding distance. This was because the 1.23 m^3/cycle average loading volume of the mini-forwarder forwarding operations by the private logging contractor were less than the 2.48 m^3/cycle average loading volume of the mini-forwarder forwarding operations by the Forest Owners' Association. A further reason is that the loading operations were conducted manually at this study site while the Forest Owners' Association used a mini-grapple-loader. The unloading operations were conducted with truck cranes at both sites (Fig. 1). Melemez et al. (in press) reported average productivity for the five alternative extraction methods with 100 m skidding distance were 3.80, 6.24, 2.80, 5.25 and 10.09 m^3/h for the methods of skidding by animal power, skidding with farm tractor, hauling with farm tractor, hauling with forest tractor and extraction by skyline, respectively. Spinelli and Magagnotti (2012) reported extraction productivities of a 70 kW farm tractor with a 15 m winching distance and 100 m skidding distance were about 4.0, 5.0, 6.5 and 7.8 m^3/h for 0.1, 0.5, 1.0 and 1.5 m^3/cycle, respectively. Therefore, the productivity of the mini-forwarder forwarding operations was similar to the productivity of the farm tractor skidding operations although the operation systems including operators and machines and the stand conditions were different.

According to costs shown in Fig. 4, system 4 with the mechanized operational system conducted by the Forest Owners' Association was the system with the highest cost on small forestry operational sites with small stem volumes. Conversely, small-scale systems operated by a private logging contractor and an individual forest owner could be effective on small site areas. This was because mechanized operations require a significant capital investment, which often exceeds the capacity of non-industrial operators as reported by Suzuki et al. (2009) and Spinelli et al. (2010).

Suzuki et al. (2009) just conducted estimations in the case of the labour costs of an individual forest owner with zero because of a self-employed operator. This study conducted estimations in the case of the labour costs of an individual forest owner of 1,300 yen/h same with the labour costs of a private logging contractor and the Forest Owners' Association in addition to the case of the labour costs of an individual forest owner are zero. As a result, system 5 with manual logging and light truck had the highest cost, followed by system 2 with manual logging and 4 t truck (Fig. 4). Therefore, this study revealed that manual logging with other than a self-employed operator was not profitable for an individual forest owner. Furthermore, transporting operations with light truck was also costly, especially with longer transporting distances. This was similar to the result of Suzuki et al. (2009).

The individual forest owner without machinery could play an important role in logging residue extraction on such small, fragmented and scattered forests all over Japan as well as in some other regions of the world. However, extraction distances of manual logging would be short and labour loads would be heavy. Therefore, a forester who advised individual forest owners should support individual forest owners to introduce and use mini-forwarders to reduce labour loads and stable supply of logging residues to a woody biomass power generation plant.

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